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Wind Turbines for Irrigation Pumping

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Irrigation pumping using modern wind turbines has been the objective of research at Bushland, Texas. A vertical-axis and a horizontal-axis turbine were tested in a mechanical wind-assist mode and a horizontal-axis, electrical-output turbine was tested in an electrical-assist mode. Data from all turbines indicated that power produced was normally less than expected, but was adequate for irrigation pumping. Many operational problems were encountered, but all were overcome with little difficulty. The Southern Great Plains have sufficient winds to power irrigation pumps when a mixture of winter and summer crops are grown. One of the major advantages of wind-assist pumping for the irrigation farmer is that he can easily retrofit the wind turbine to his existing irrigation system. Results indicated that as much as 40% of the present energy consumed in irrigation pumping can be generated by wind power.

Introduction

WINDMILLS have been used for centuries to grind grain and pump water. In the United States, windmills and wind generators were used extensively until the 1940s, when they were replaced by electricity from rural electric cooperatives. Many windmills are still used today to pump water for livestock and domestic use. These units normally produce a maximum power of 1 kW and pump less than 3 m^3/h. However, new wind machines are being developed that produce 10-200 kW. These new machines are capable of powering the large pumps used for pumping irrigation water.

Irrigation, a major energy user in agriculture production, required an estimated 87 billion kWh of energy in 1978. About 12% of our cropland is irrigated, and these lands produce about 27% of the agricultural products in the United States. Only energy used for manufacturing fertilizer followed by tractor and truck fuel use exceeds that used in irrigation, making irrigation the largest on-farm, nonvehicular user of energy in agriculture.

In the Southern Great Plains, irrigation pumping accounts for about 50% of the energy used on irrigated farms. In this area, over 100,000 pumps are lifting water at least 50 m and requiring between 20 and 100 kW, with an average of 40 kW. Flow rates usually range between 100 and 500 m^3/h. Most irrigation pumping is done with electricity, natural gas, or diesel fuel. All are rapidly increasing in price and decreasing in supply, thus creating interest in new or alternative power sources, especially wind, because most irrigated areas are located in or near windy regions.

Experimental wind-powered irrigation systems have been undergoing tests for the last two years.[1] One pumping system, called the wind-assist system, uses both a wind turbine and an electric motor to power a conventional turbine irrigation pump. This system has been examined using a vertical- and a horizontal-axis wind turbine. Another pumping system uses a wind turbine to generate electricity, and an irrigation pump powered by electricity. Specifications of the three wind turbines tested are given in Table 1.

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Vertical-Axis Wind-Assist Pumping

This pumping system used both a vertical-axis wind turbine and an electric motor to power a vertical turbine pump (Fig. 1). The electric motor was sized to operate the pump on a stand-alone basis and ran continuously when irrigating. The wind turbine was coupled to the pumpshaft through an over-running clutch and combination gear drive and furnished power only when the windspeed exceeded 6 m/s. The wind turbine thus reduced the load on the electric motor rather than replacing the motor.

Wind Turbine

The Darrieus vertical-axis wind turbine was designed to produce 40 kW in a 15 m/s wind (Fig. 2). The rotor was 16.7 m high and had an equatorial diameter of 11.5 m. It set on a 9.1 m stand-alone steel tower and was supported at the top by four 2.2 cm galvanized steel cables. The chord length of the symmetrical airfoils forming the blades was 356 mm. A 3.7 kW starter motor was required because Darrieus wind turbines are not reliably self-starting.

The wind turbine was designed to operate at 90 rpm, but the pump operated at 1780 rpm. For this reason, a high-ratio speed increaser was required in the drive train. A right-angle speed increaser and a timing belt were used to give a speed ratio of 1:19.8. With this ratio, the 90 rpm rotor speed was matched to a 1780-rpm pump speed.

Since wind power is intermittent, a clutch was required which engaged only when the wind turbine was producing power. The turbine output shaft was connected to the combination gear drive through an over-running clutch. The over-running clutch allowed the electric motor, combination gear drive, and pump to operate independently of the wind turbine. The wind turbine could be stopped or could coast below operating speed without affecting the pump. When the turbine reached its operating speed of 90 rpm, the over-running clutch engaged to transmit wind power into the combination gear drive.

A 75 cm disk brake with three calipers was used for normal or emergency shutdown of the rotor.

Pump and Motor

A 20 cm vertical turbine pump, installed in the well in 1964, was used without modification in the pumping system. The well produced approximately 91 m^3/h, and the total dynamic head on the pump was 100 m.

Table 1 Specifications of wind turbines tested

	DAF 40	Wingen 25	Carter 25
Manufacturer	Dominion Aluminum Fabricating[a]	Wind Engineering Corporation[a]	Jay Carter Enterprises[a]
Type	vertical, Darrieus	horizontal, downwind	horizontal, downwind
Size			
Diam, m	11.5 × 16.7	10	10
Rating, kW	40 (30)	23	23
Windspeed, m/s	10	10	10
Rotor			
No. blades	2	3	2
Airfoil	0015	4415	23015, 23012
Chord, cm	36	46	
Material	Al, extruded	Al, dacron	fiberglass
RPM	90 (81)	67	120
Tower Ht., m	9.1	18	17 guyed
Installed cost, $	75,000	29,000	13,000

[a] Neither USDA nor AEI endorse these products, but are given only for information and clarity.

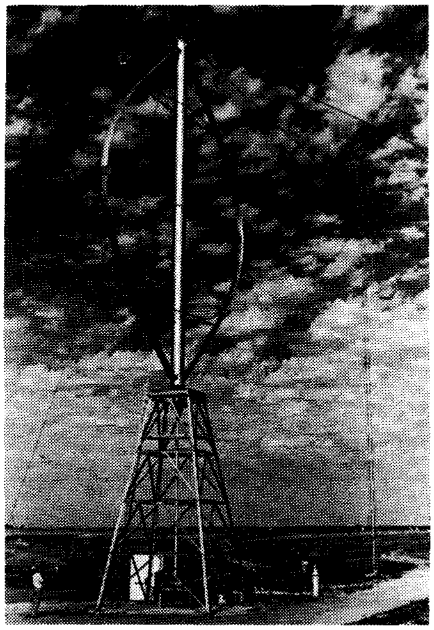

Fig. 2 Vertical-axis wind turbine—DAF 40.

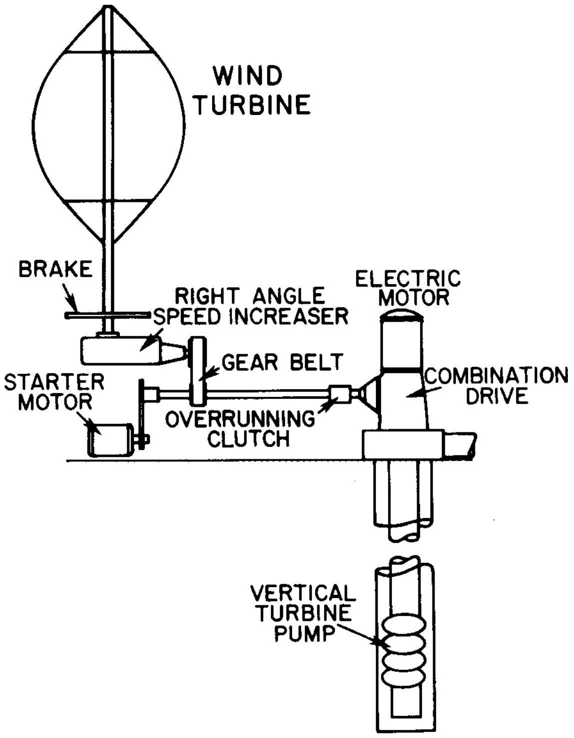

Fig. 1 Schematic of vertical-axis wind-assist pumping system.

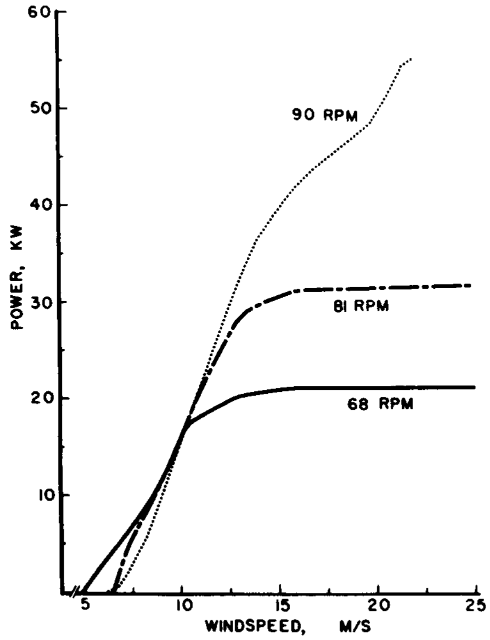

Fig. 3 Power produced by DAF 40 at three different turbine speeds.

The induction motor used to power the pump was a three-phase vertical, hollow-shaft type normally used with vertical turbine pumps. The 56 kW motor had a full-load operating speed of 1780 rpm. In addition to being the primary power source, the electric motor controlled the speed of the wind turbine. When the over-running clutch engaged, the wind turbine partially unloaded the electric motor. Since the wind turbine provided less power than the motor, the motor speed varied between 1780 rpm and 1800 rpm, the synchronous speed of the motor. This maintained the rotor speed at 90 rpm or slightly more.

Performance Data

The wind turbine was initially operated at 68 rpm for a shakedown phase. Later, the timing belt pulleys were changed for turbine operation of 90 and 81 rpm. Figure 3 shows the power produced at each of the turbine speeds tested. The peak power measured at 68 rpm was 21.1 kW when the windspeed was 16.5 m/s. Correspondingly, peak power at 81 rpm was 30.9 kW when the windspeed was 16.5 m/s, and at 90 rpm, it was 52.3 kW at a windspeed of 19.5 m/s. The cut-in windspeed was also affected by turbine speed, it was 5 m/s at the 68 rpm, and 6 m/s at 90 rpm.

System operating performance with a rotor speed of 90 rpm is summarized in Fig. 4. The curves are a regression of all data collected in several tests between June 1978 and July 1979. Details of these data were discussed by Clark et al.[2] and Clark and Schneider.[3]

The curves show the operating characteristics of the wind-assisted pumping system with windspeed ranging from 6 to 20 m/s. The rotor output was measured with a torque transducer at the base of the rotor centershaft. Turbine system power was measured with a torque transducer in the high-speed

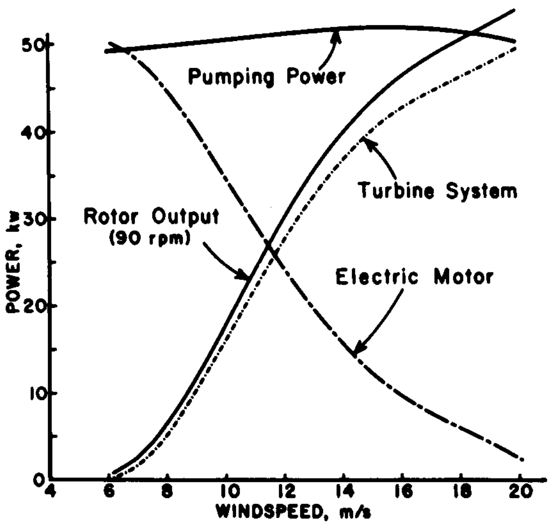

Fig. 4 Wind turbine system power, rotor output, electric motor power, and pump system power when the rotor speed is 90 rpm.

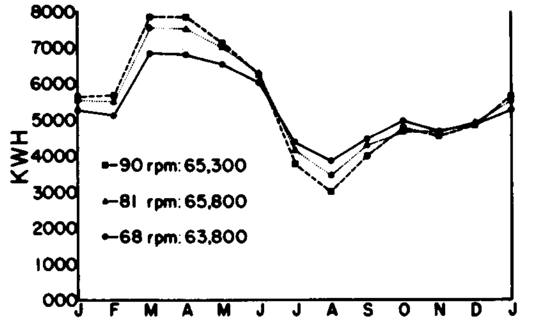

Fig. 5 Predicted energy output for DAF 40 at three different operating speeds.

horizontal shaft. The rotor output and the turbine system power delivered to the pump are shown by the two almost parallel curves. The difference between the two curves represents the losses in the speed increaser; it averaged about 9%. The power used by the electric pump motor was reduced from 50 kW for full-load operation below 6 m/s to 3 kW when the windspeed was 20 m/s. The average power consumed by the electric motor was 28 kW during the time the wind turbine was operating. Pumping power is the sum of the turbine system and electric motor power. During the test period, the wind turbine saved 45% of the electricity normally used.

Eleven years of windspeed data from the Amarillo National Weather Service Station were analyzed to determine the monthly power production at each operating speed. These data showed that the operating speed had little effect on annual energy production (Fig. 5). Annual energy production ranged from 63,800 to 65,800 kWh for operating speeds of 68 and 81 rpm. However, turbine speed did affect the monthly values, especially in the spring and summer. To achieve maximum annual power, the operating speed should be changed to coincide with the season.

Discussion

The vertical-axis wind turbine was successfully coupled to an existing irrigation pump by installing a combination gear drive between the pump and electric motor. Several problems in erecting the wind turbine were encountered, but relatively few problems were encountered during operation. Shipping damage and missing parts were major problems during erection. The two major problems during operation were failure of the top bearing and the loss of a strut pin. The top bearing failed at about 100 h operating time because of shipping damage and the strut pin ejected after the retaining ring failed.

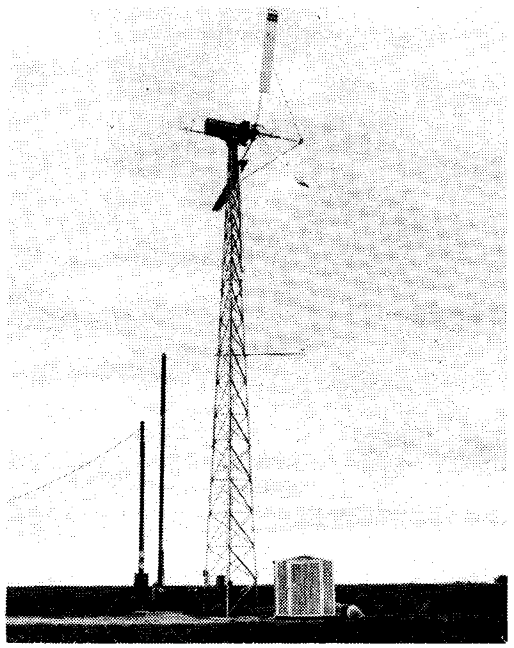

Fig. 6 Three-bladed, horizontal-axis wind turbine—Wingen-25.

Horizontal-Axis Wind-Assist Pumping

To maximize the return on his investment, the farmer needs to utilize the wind turbine whenever the wind is blowing. Such a system was field tested in conjunction with a rural electric cooperative and a farmer.[4]

Wind Turbine

The wind system operates in two different modes: wind-assist mode when water is being pumped, or electrical generating mode (Fig. 6). The three-blade, horizontal-axis wind turbine is mechanically connected to an induction motor (18 kW) through an over-running clutch (Fig. 7). When water is being pumped, the wind turbine supplements the power from the electric motor, thereby reducing power consumed from the utility line. If enough power is available from the wind turbine, it is possible to increase the speed of the induction motor over its synchronous speed, thus causing the motor to act as a generator.

When irrigation water is not needed, the drive shaft is manually disconnected, the wind turbine drives the electric motor solely as a generator, and power is fed into the utility line.

Performance Data

Shakedown tests began in June 1979 and automatic operation began in August. The wind turbine operated for 1140 h with 860 h in wind-assist pumping mode, and 280 h in electric generating mode. Only 150 kWh were fed into the utility line because of low windspeeds in August and September. The windspeed was above the cut-in windspeed of 6 m/s for only 30 h during electric generating mode tests. The power output vs windspeed is shown in Fig. 8.

The turbine was originally designed to operate at 100 rpm, but the drag losses due to the struts (approximately 4 kW) were larger than expected. By lowering the operating speed, the drag losses were reduced to 1 kW and cut-in windspeed was reduced. The disadvantage of reduced operating speed was reduced power output; however, the turbine power was still larger than the load of the well, so the change caused no major operational problems.

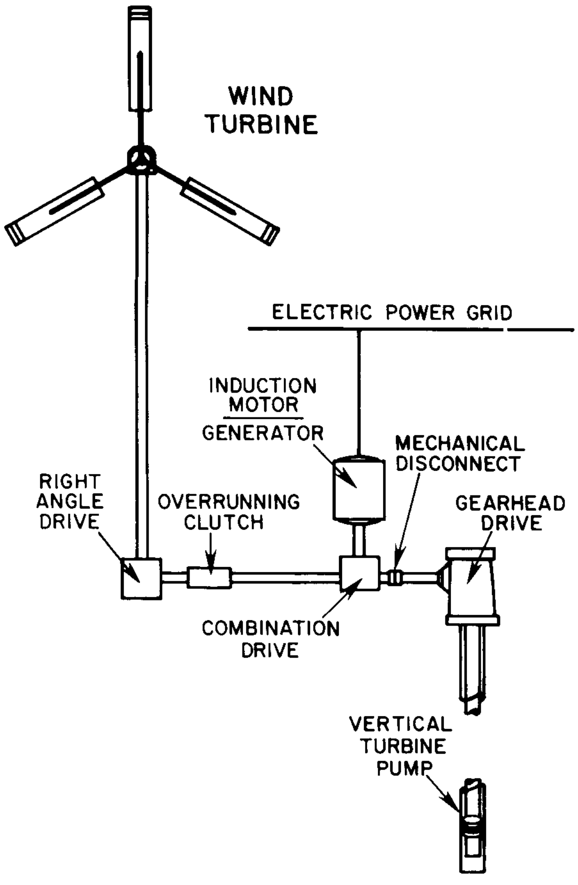

Fig. 7 Schematic of wind-assist irrigation and off-season power generation using Wingen-25.

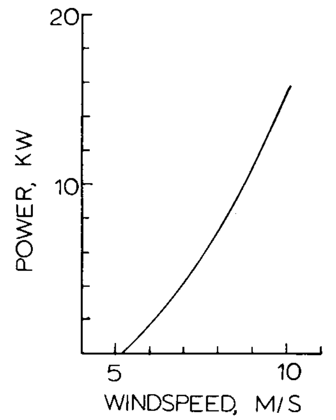

Fig. 8 Power produced by Wingen-25. Curve is regression analysis of data collected.

Discussion

As with most developmental projects, delays were experienced, repairs were needed during the shakedown phase, and a major failure occurred in October with the loss of one blade. It is important to know the characteristics of the load, in this case the well. After the well was acidized to remove restrictions in well screen, which increased the flow, the increased load caused the three-way gear box to fail, and the gear had to be replaced with a larger one.

The loss of a blade was caused by a faulty fabrication. A deep weld at the aluminum spar produced local crystallization and destroyed the strength of the material, thus leading to the failure. Upon removal of the nacelle, we found cracks at the same locations on the other blades. A new set of blades with a longer radius, larger chord, and a different fabrication technique was installed in December 1979. Because of problems with the original control system (relay logic) and connection of the control leads, a microprocessor has been installed.

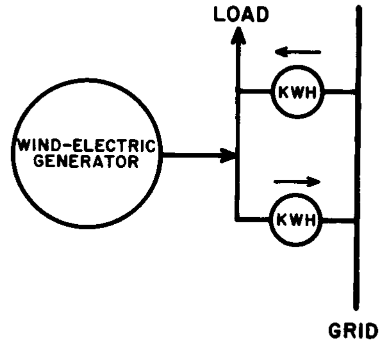

Fig. 9 Schematic of wind assist electrical connection system using Carter-25.

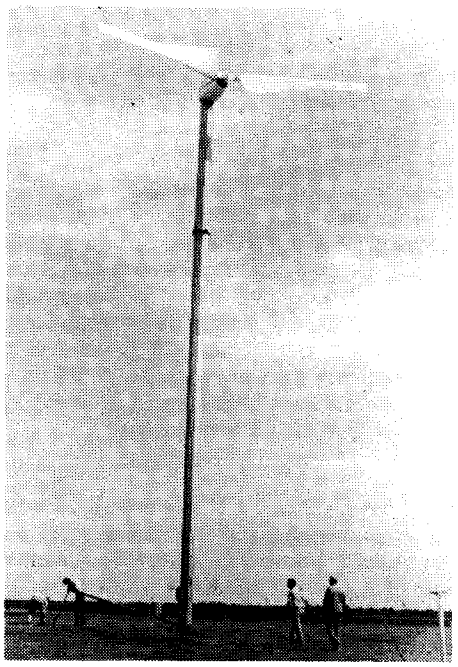

Fig. 10 Two-bladed, horizontal-axis wind turbine—Carter-25.

Horizontal-Axis Electric Connection

A third system, induction generator driven by a wind turbine, can assist or supplement an electric load, in this case an electric powered pump (Fig. 9). This system does not require modification of the well head or pump, and the location of the wind turbine with respect to the well is more flexible. In addition, power can be generated and fed into the utility grid when water is not being pumped. Presently a horizontal-axis wind turbine is being tested with all the power being fed into the utility grid (Fig. 10).

Wind Turbine

This 25 kW wind turbine is unusual in that both the spar and blades are fiberglass. The blades are fixed pitch, and rotor speed is controlled by the speed of the generator. However, power output at high windspeeds is also limited by unloading due to the flexibility of the spar. In addition, torsional flexibility of the spar along with centrifugal motion cause the blades to pitch up and stall for overspeed control when electrical power is lost. Installation and maintenance costs are reduced by the use of a gin pole for raising and lowering the unit.

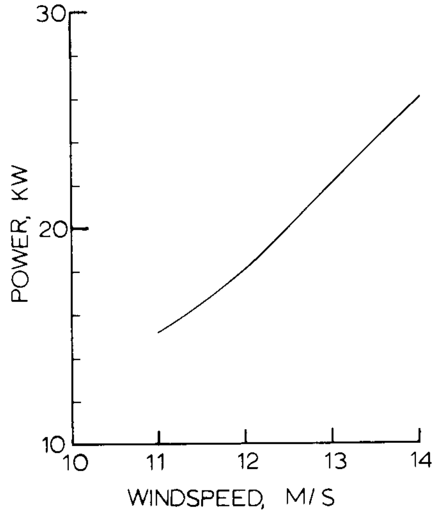

Fig. 11 Power produced by Carter-25. Curve is regression of limited data, 15 min averages for windspeed and power.

Performance Data

Presently, the only data available are kilowatt hours used, kilowatt hours produced, and largest 30 min average kilowatt hour demand. The unit has operated almost continuously from September to December 1979 and has generated 6500 kWh. The largest 30- min power output was 30.4 kW, and many periods when output was 20 to 25 kW were also recorded. Preliminary data of power output is shown in Fig. 11. As soon as a watt transducer is received, it will be installed and connected to the data acquisition system.

Discussion

As with the other system, we had developmental problems. The coning angle was changed from 15 to 5 deg because the forces at windspeeds above 9 m/s started to change the pitch of the blades. The pitch of one blade would be different from that of the other and the unit would shut down due to vibration. The unit has successfully operated in windspeeds up to 30 m/s since modification.

A minor problem was that one of the dash pots for overspeed control would not let the blade reset to running position after it had changed pitch. Also, vibration caused a short circuit at the breaker box, which destroyed an electrical connection.

Conclusions

All three of the wind turbines tested for irrigation pumping produced enough power to pump water for crops. The vertical-axis unit provided up to 52 kW at 20 m/s, where as one horizontal unit produced over 25 kW at 14 m/s, and the other 16 kW at 10 m/s. Because of the need for irrigation water during critical growth periods for crops, we used a wind-assist concept for testing these wind turbines.

The wind-assist pumping concept has several advantages over a stand-alone wind system: 1) water can be pumped and distributed to the crops during critical water-use periods regardless of windspeed; 2) a constant pump speed is maintained for good pump efficiency and optimum well yields; 3) the system is easily adapted to existing irrigation pump installations without exchanging pumps or other existing equipment; and 4) a consistent water flow permits efficient application of irrigation water and good water management. The shortcoming of the wind-assist concept is that it requires two power sources and in the systems tested, a connection to the electric utility with associated demand charges was needed.

Our results have shown that is is important to match the design operating speed of the wind turbine to the peak of the wind power distribution. This needs to be done to maximize the power produced by the system.

In the Southern Great Plains, irrigators usually pump about 2000 h during an irrigation season. Most of the pumping is done in March through October, depending on what crops are grown. From an analysis of Amarillo National Weather Service records, there are about 3000 h when windspeed exceeds the cut-in speed of these wind turbines. More energy could be saved by farmers growing more winter wheat than corn or grain sorghum because wheat has its peak water-use period during April and May, which are good windpower months. We feel wind-assist pumping has potential for providing an alternate source of energy for irrigated agriculture in areas with average windspeeds exceeding 6 m/s.

Acknowledgment

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